Design of an L-Band Microwave Radiometer with Active Mitigation of Interference

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RFI Issues for Microwave Radiometers

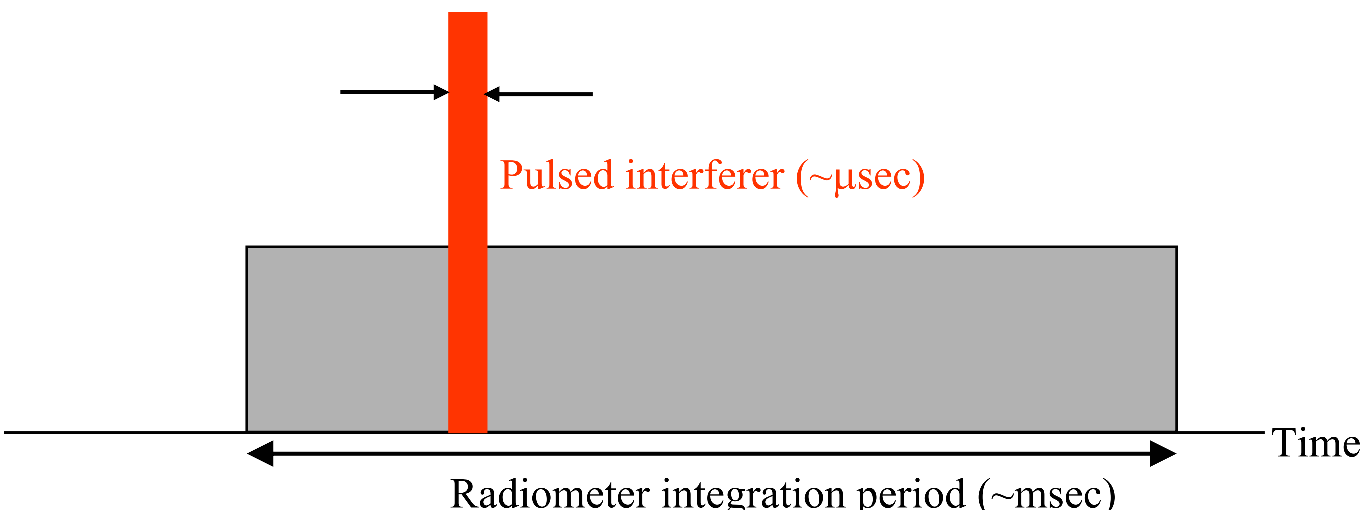
- A microwave radiometer is a sensitive receiver measuring naturally emitted thermal noise power within a specified bandwidth
- Human transmission in many bands is prohibited by international agreement; these are the “quiet bands” ideal for radiometry
- L-band channel quiet band is 1400-1427 MHz: larger bandwidth would improve sensitivity if RFI can be addressed. Ocean salinity missions require extremely high sensitivity.
- Even within quiet band, RFI has still been observed - possibly due to filter limitations or intermodulation products
- Radiometer designs with improved interference mitigation capabilities are critical for future missions

Outline

- Problems with traditional radiometer designs
- Interference suppressing radiometer design
- Initial results and experiment plans
- Airborne RFI surveys
- Conclusion

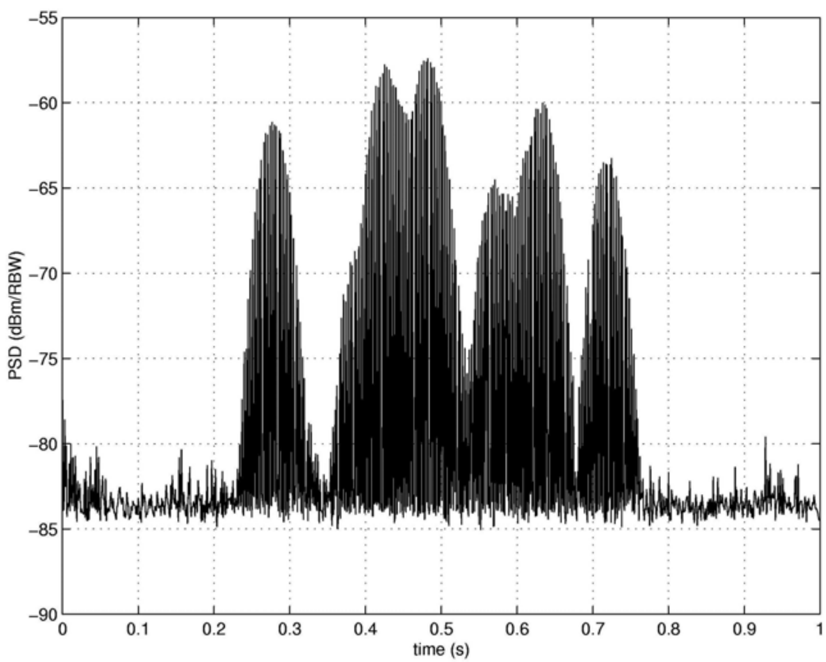
Pulsed Interferers

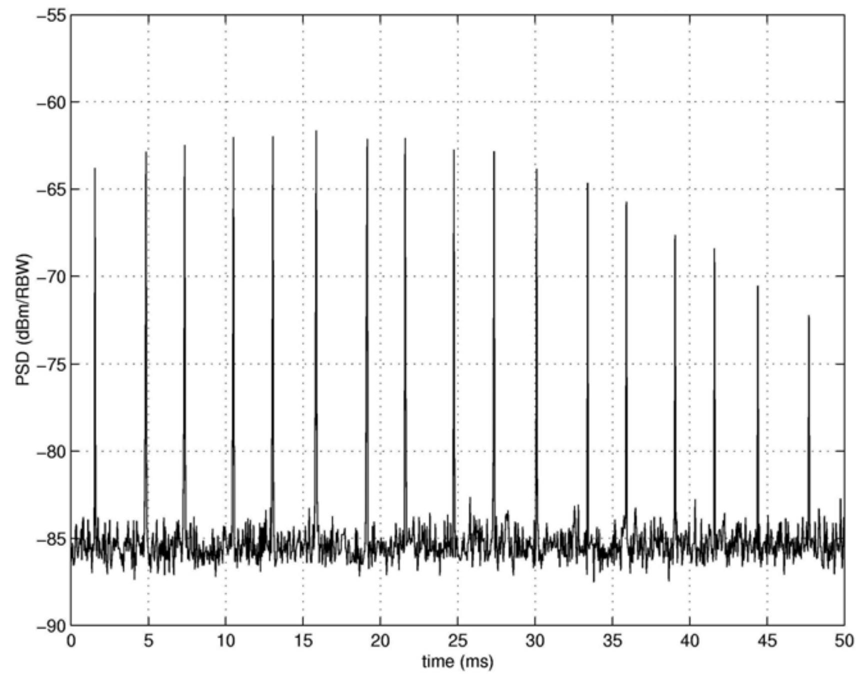
- Typical radiometer is a very "slow" instrument: power received is integrated up to msec scales by analog system before being digitized
- However, many RFI sources are pulsed, typically with microsecond scale pulses repeated in millisecond scale intervals
- A single microsecond scale pulse within a millisecond scale integration period can corrupt the entire measurement
- A radiometer operating a faster sampling rate has the potential to identify and eliminate microsecond scale features without sacrificing the vast majority of the millisecond scale data



Example of Pulsed RFI

- Time domain ("zero span") spectrum analyzer measurements from ESL roof with low-gain antenna: 1331 MHz +/- 1.5 MHz

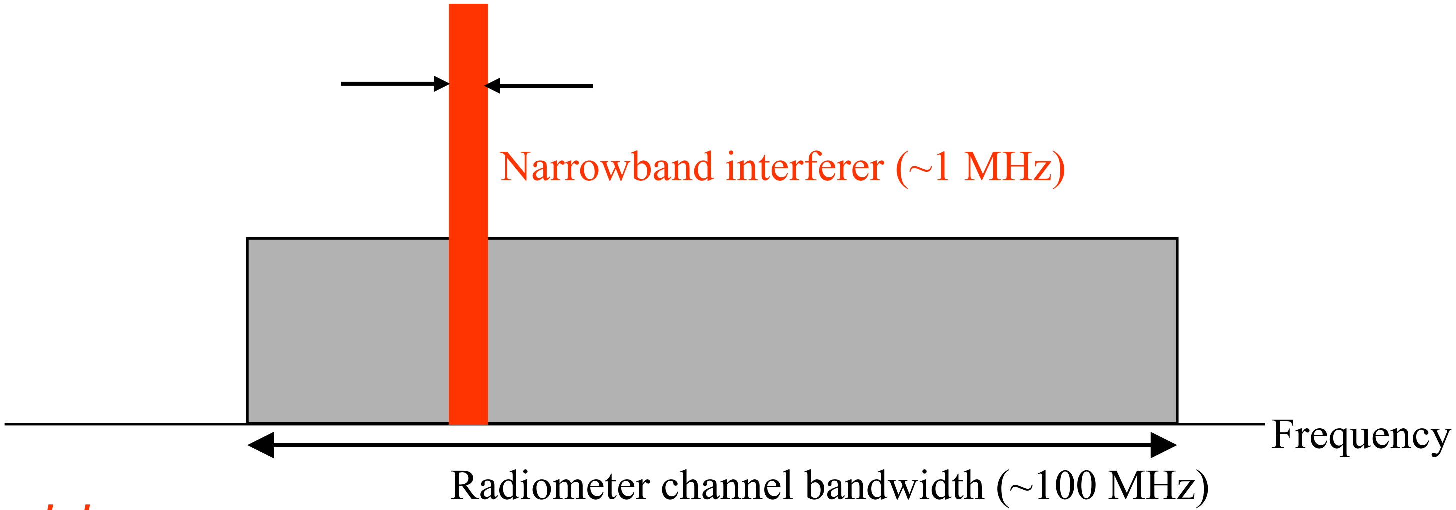




- ATC radar in London, OH (43 km away): PRF 350 Hz, 2 usec pulses plus multipath, approximate 10 sec rotational period

Narrow-band Interferers

- Typical radiometer also has a single, large bandwidth channel (20 MHz or more): total power within this channel is measured
- However, many RFI sources are narrow-band (<=1MHz),
- Again, a single 1 MHz interferer within the channel can corrupt the entire measurement
- A radiometer operating with many much smaller channels has the potential to identify and eliminate narrowband interferers without sacrificing the vast majority of the bandwidth

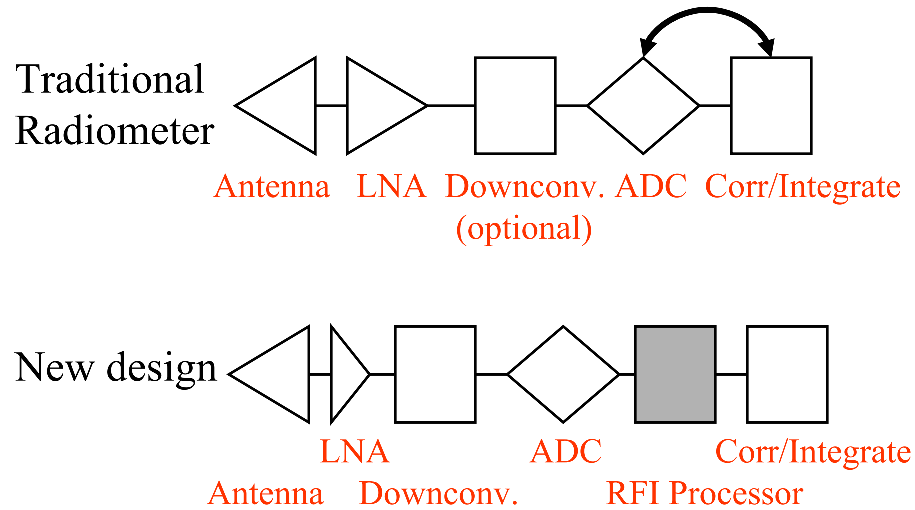


Digital Receiver with Interference Suppression for Microwave Radiometry

PIs: Joel T. Johnson and Steven W. Ellingson, The Ohio State University

Description and Objectives

Future sea salinity and soil moisture remote sensing missions depend critically on L-Band microwave radiometry. RF interference is a major problem and limits useable bandwidth to 20 MHz. An interference suppressing radiometer could operate with a larger bandwidth to achieve improved sensitivity and more accurate moisture/salinity retrievals.



Approach

A prototype radiometer will be designed, built, and used to demonstrate operation in the presence of interference. The design includes a processing component to suppress interference.

Schedule and Deliverables

Year 1: Complete design and begin construction

Year 2: Finish construction and begin tests

Year 3: Demonstrations and space system design

Co-I's/Partners

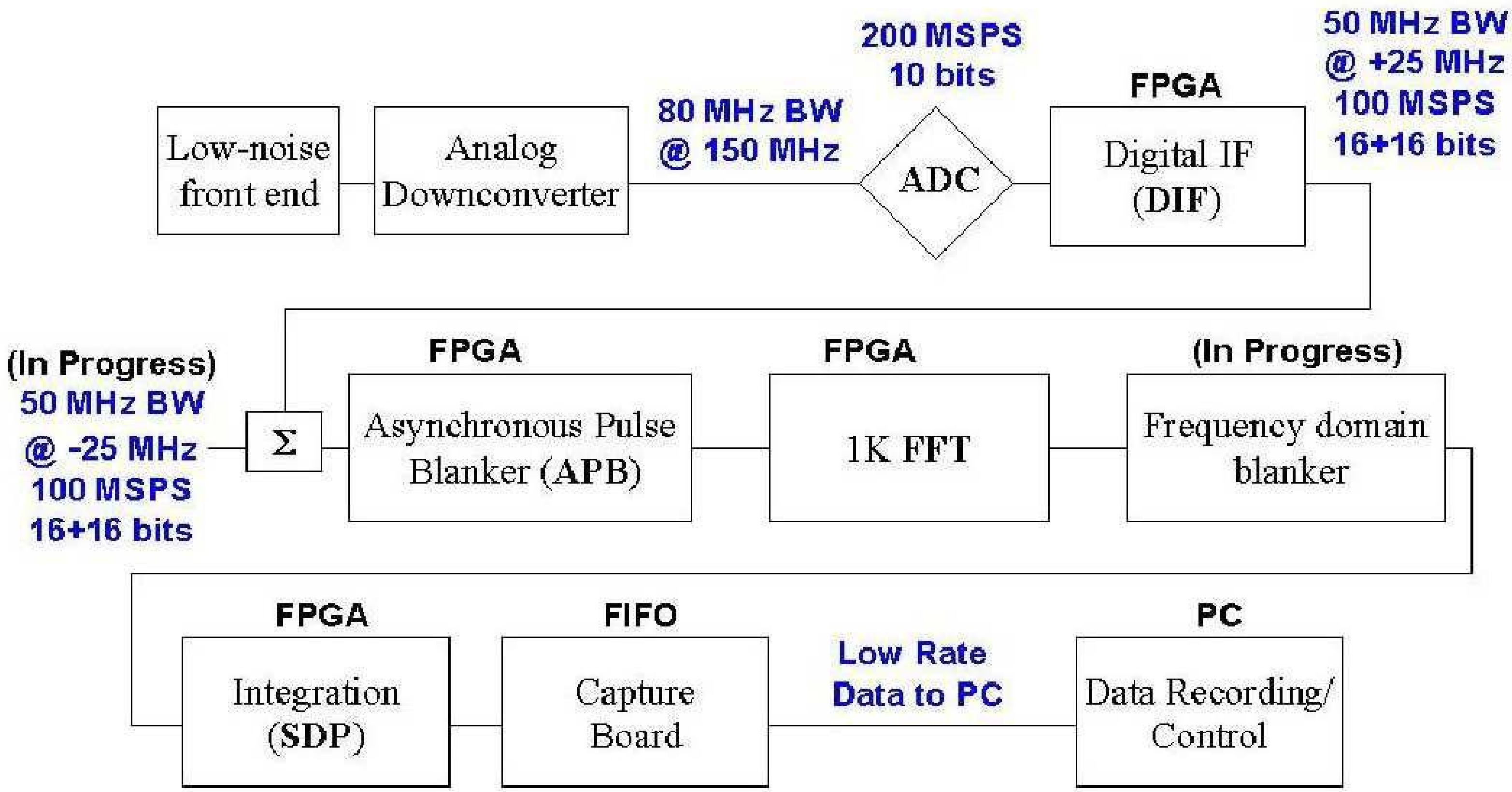
Dr. Grant Hampson, OSU

Application/Mission

Results will apply to all future microwave radiometer missions. Future L-band soil moisture and salinity missions are primary focus.

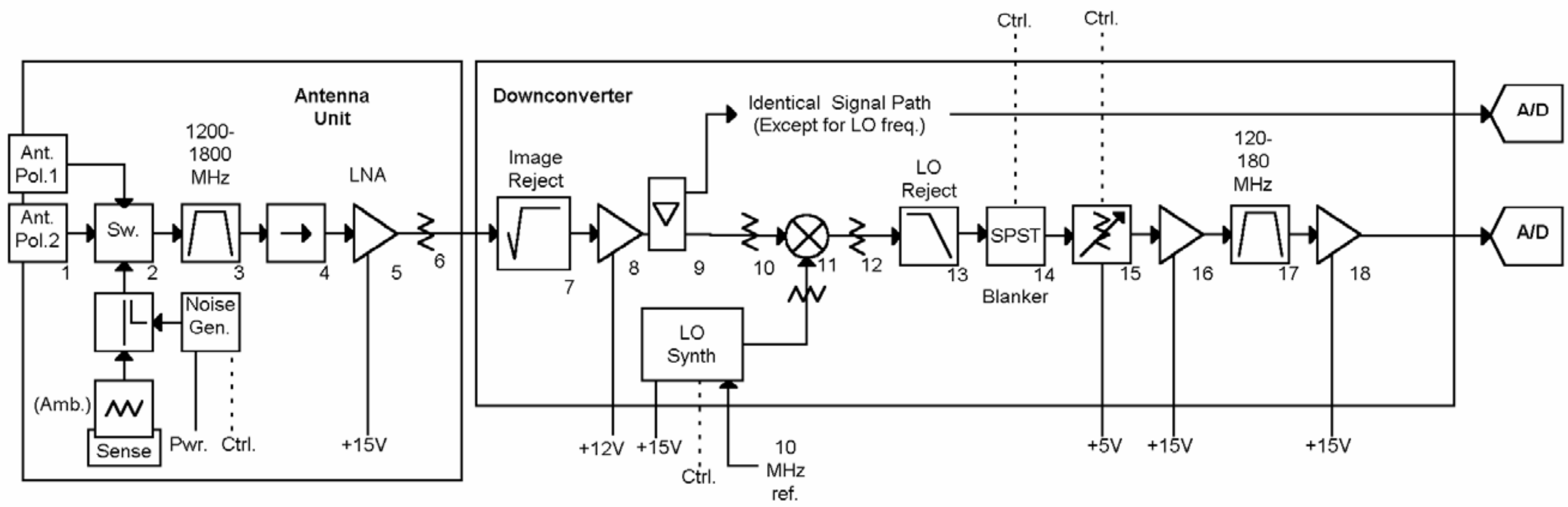
TRL levels: from 3 to 5

System Block Diagram



Radiometer Front End/Downconverter

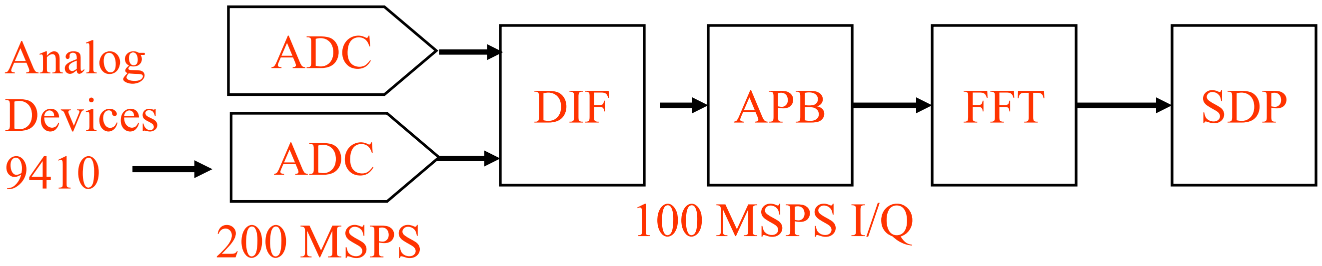
- Relatively standard super-het design: Tsys approx. 400K



- 100 MHz split into two back-end channels
- Stability: analog gain reduced by high dynamic range ADC, low order analog filters, internal cal loads
- Temperature sensing of terminator + thermal control system

Digital Back-End

- System design includes digital IF downconverter (DIF), asynchronous pulse blanker (APB), FFT stage, and SDP operations



- Most blocks on separate boards to simplify testing and reconfiguration
- Microcontroller interface via ethernet for setting on-chip parameters
- Second prototype uses Altera "Stratix" FPGA’s: apprx 10000 LE, $260
- Designs for all components complete; DIF, APB, FFT, SDP, and capture card initial implementations functioning

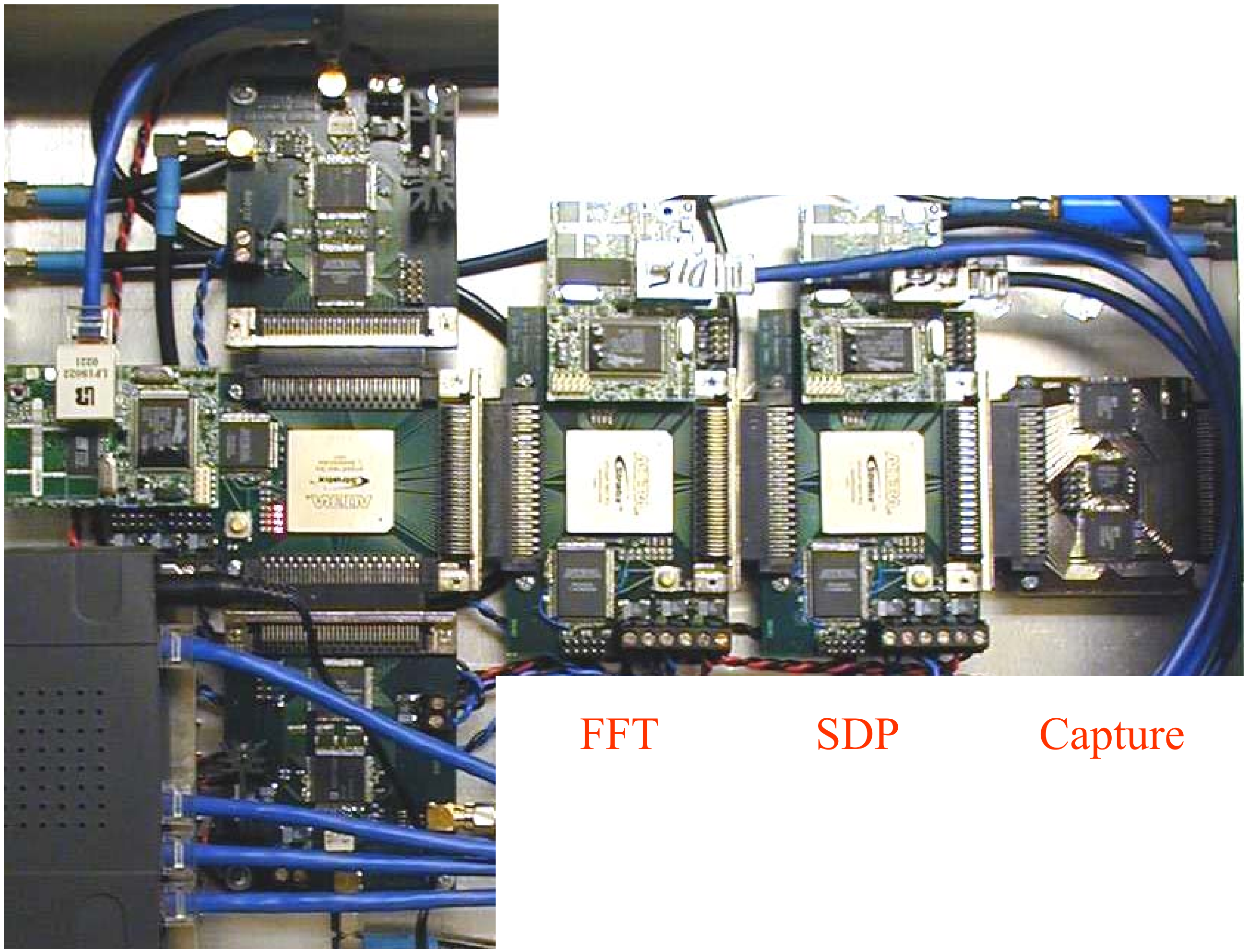
Current Digital Back-End Implementation

- Modular form used for processor boards: note microcontrollers
- EEPROM's on each card for autoprogramming of FPGA's on power-up

ADC

DIF/
APB

ADC



FFT SDP Capture

Interference Suppression Algorithms

- APB updates mean/variance of incoming time domain signal; a sample > β standard deviations above the mean triggers blanker
- Blanking operates on down-stream data exiting a FIFO; blank signals before and after blanking trigger
- Parameters: blanking window size, precursor length, threshhold
- With multiple “blanking timing registers” (BTRs), additional “pulses” occurring during blanking window can trigger more blanking events

- Post-FFT: two methods
  - similar to APB, monitor per-bin mean/variance in time and blank outliers
  - unlike APB, can also blank outliers in freq. response at single time

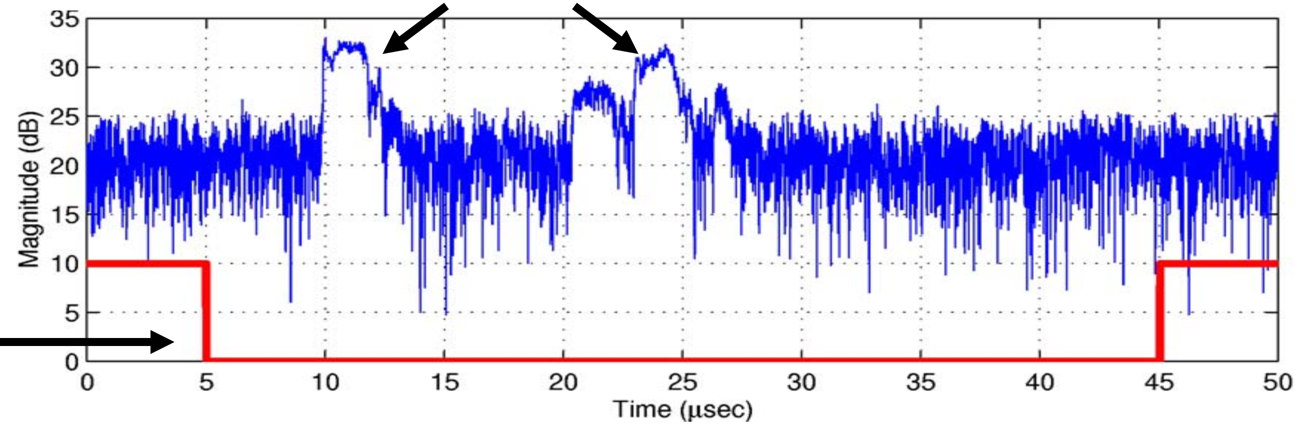
- Parametric: remove interferer based on parametric fit to a specific functional form; to be explored further

- Calibration effects corrected in real-time by appropriate scale factors

Initial Results: Time Blanking of ATC Radar

- Time domain results:

Direct path Multi-path?

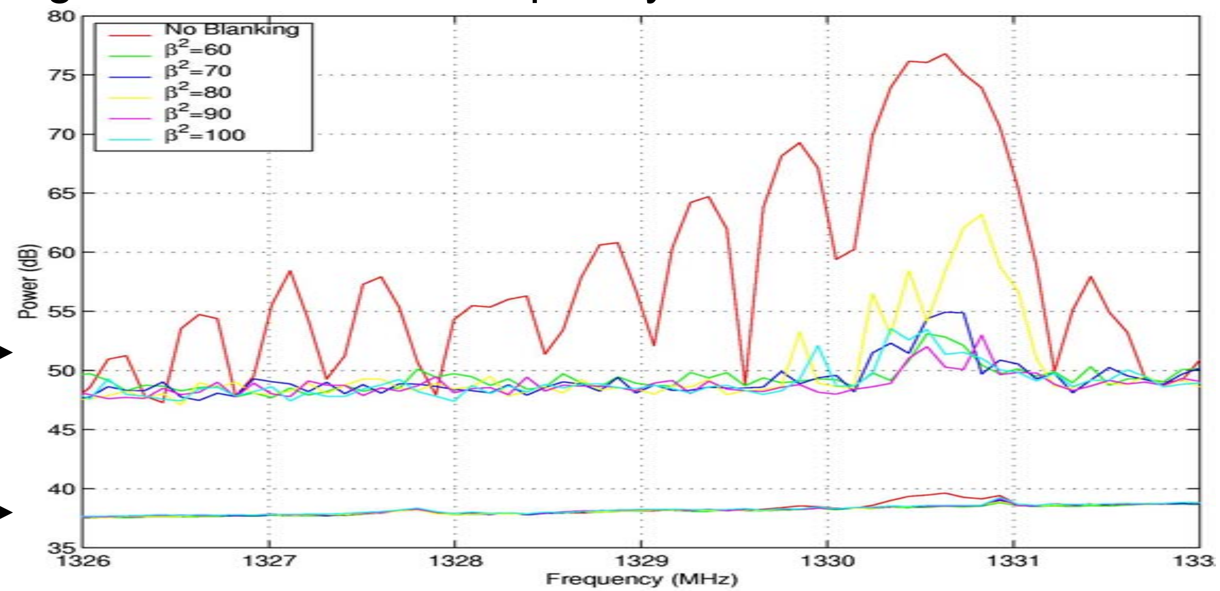


APB "Blanking" decision

- Effect of varying APB threshold in frequency domain:

"Max held" spectra

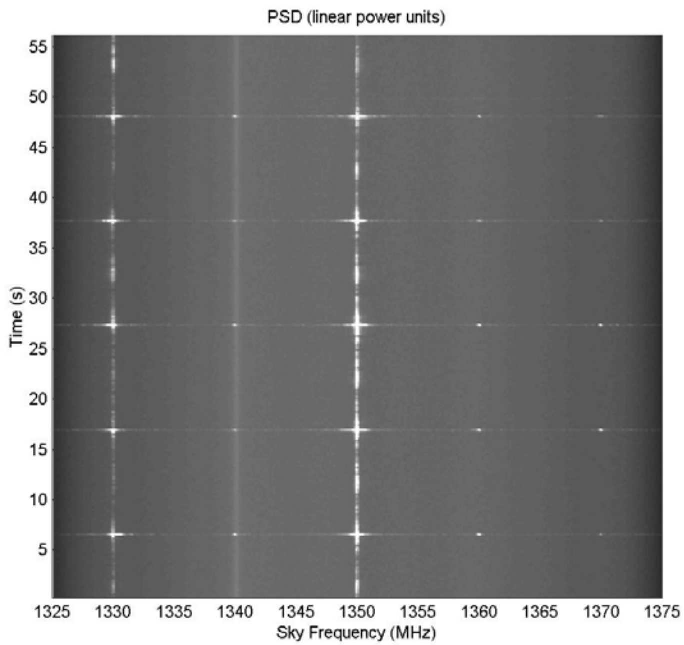
Averaged spectra

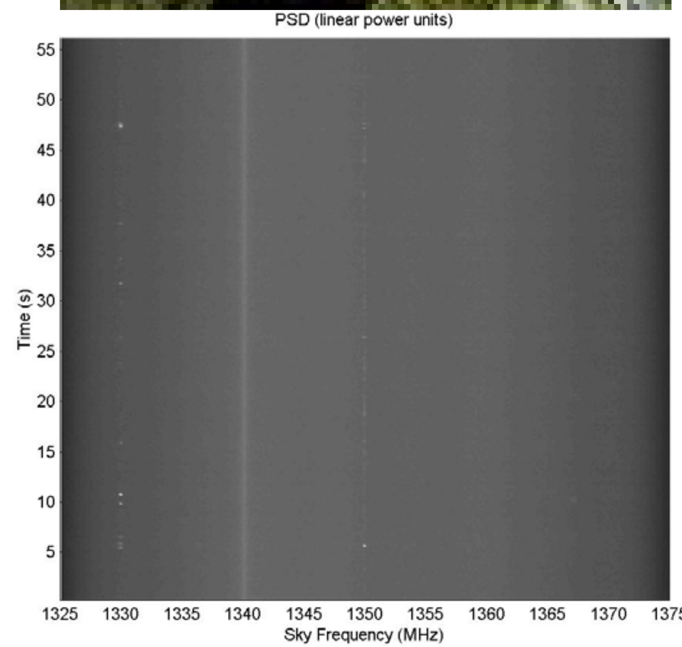


Initial Results: Blanking a Dual Frequency Radar at Arecibo using the IIP Digital Receiver

The radio telescope at Arecibo, PR suffers from RFI from distant ground-based air search radars

1325-1375 MHz spectra including digital IF, APB, FFT, and integration (42 msec)



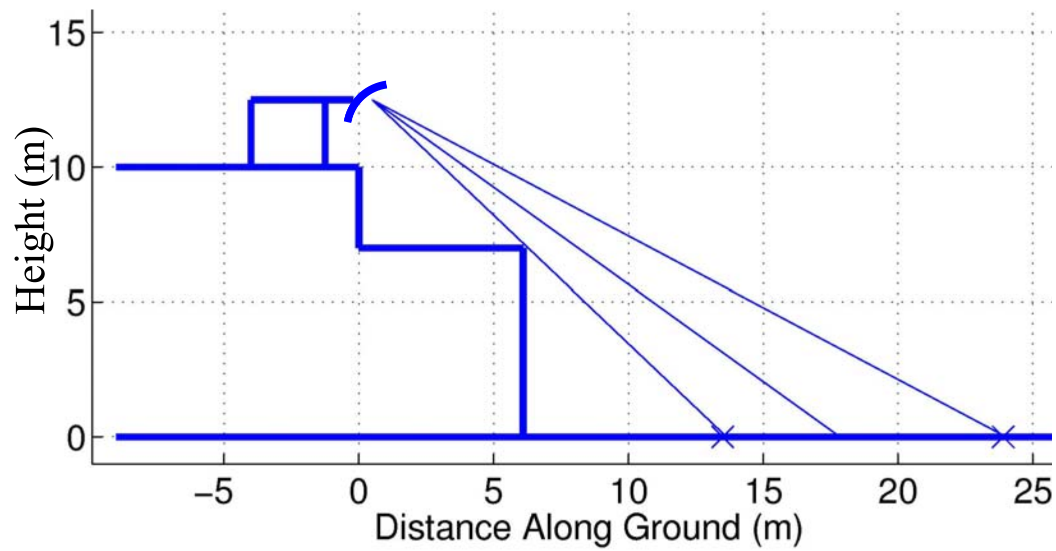


Before: ATC radar pulses visible

After: APB removes radar

Upcoming Experiments

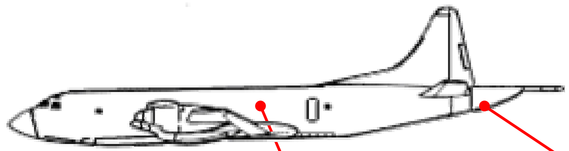
- A series of experiments with the prototype will be conducted at ESL beginning Su 03
- Observations of a large water tank; external cal sources are ambient absorbers and a sky reflector
- Initial tests in existing RFI; artificial RFI to be added as tests progress

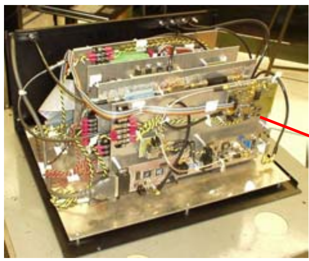


- Developing robust suppression algorithms requires detailed information on RFI in varying environments: surveys are critical!

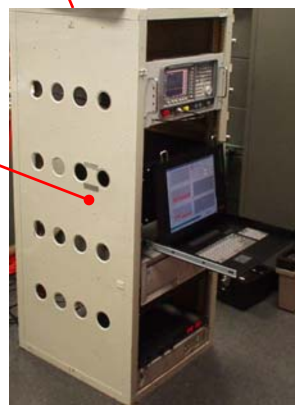
LISA: L-Band Interference Surveyor/Analyzer

S.W. Ellingson, J.T. Johnson, and G.A. Hampson, The Ohio State University





RF distribution, antenna unit control & coherent sampling subsystem



Spectrum analyzer, electronics rack & control console mounted in cabin

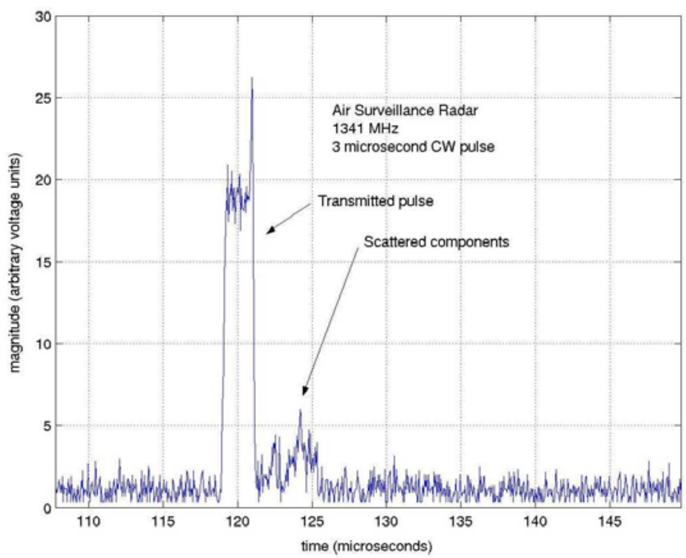
Nadir-looking cavity-backed spiral antenna w/ custom LNA & calibration electronics in tail radome

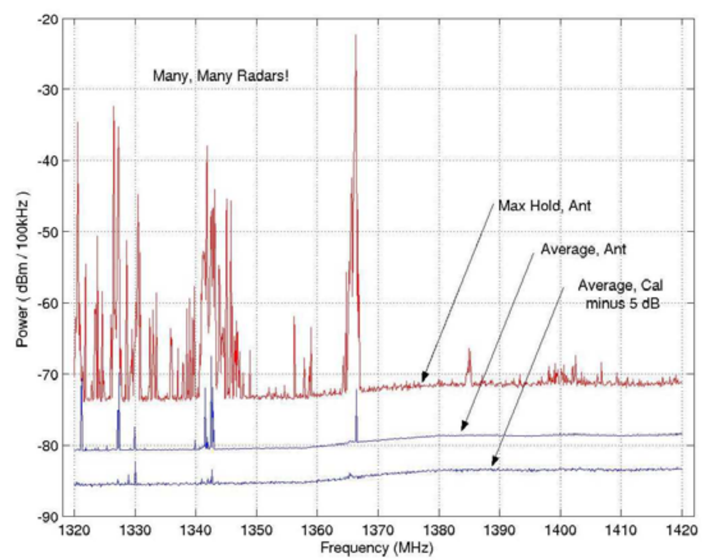
NASA's P-3 Orion Research Aircraft
Maiden LISA Flight: January 2, 2003 from Wallops Island, VA

LISA co-observes with existing passive microwave sensors to identify sources of damaging radio frequency interference (RFI)

- 1200-1700 MHz using broadbeam spiral antenna
- Spectrum analyzer for full-bandwidth monitoring of power spectral density
- 14 MHz (8+8 bit @ 20 MSPS) coherent sampling capability for waveform capture and analysis
- Flexible script command language for system control & experiment automation

Examples of RFI observed at 20,000 feet

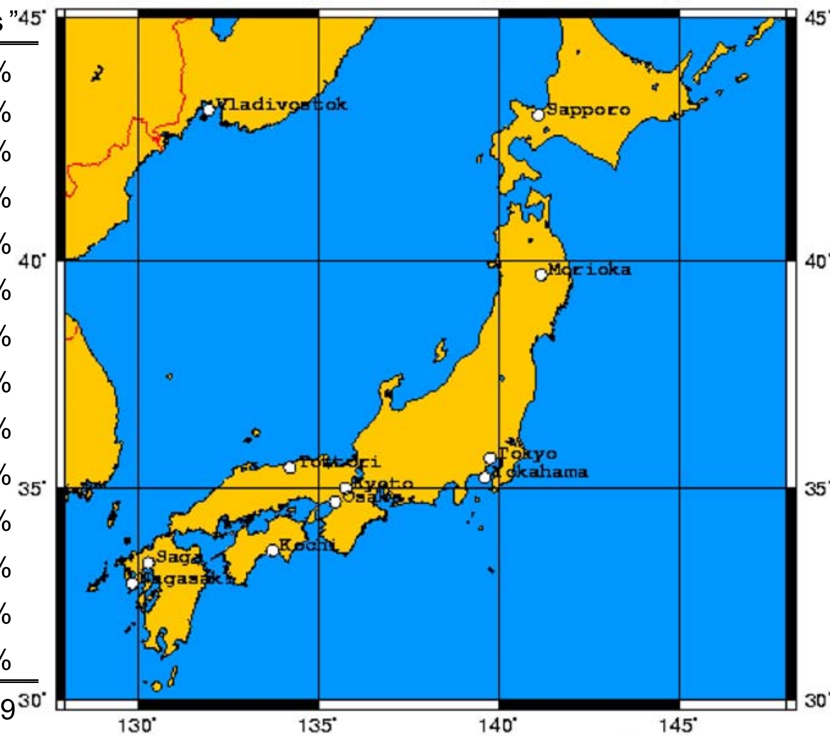




LISA Wakasa Bay Campaign

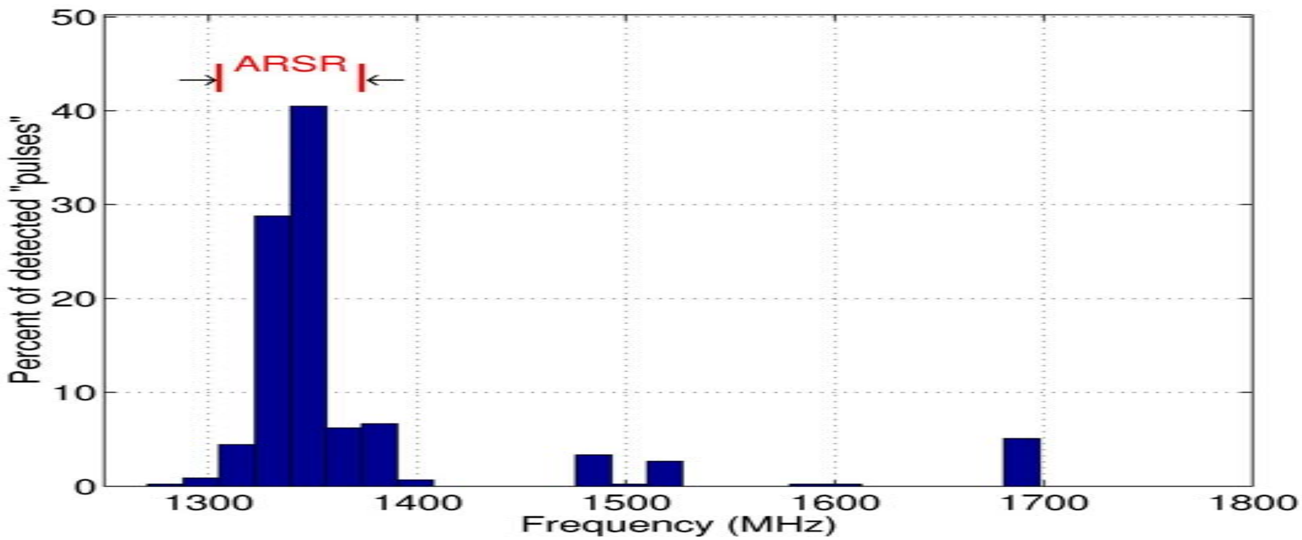
- LISA was deployed in the AMSR-E "Wakasa Bay" cal-val campaign; thanks to E. Kim (NASA) and R. Austin (Co. State) for operations
- Antenna in P-3 radome: high loss decreased sensitivity, but also reduced compression problems

Date	Description	# of files	"Pulses"
1/2	Wallops test flight	615	1.79%
1/3	Wallops to Monterey	4372	1.85%
1/4	Monterey to Kona	1616	0.06%
1/6	Wake to Japan	5287	0.15%
1/14	Sea of Japan	3987	1.58%
1/15	W. Japan	2342	2.04%
1/19	W Pacific	78	0.00%
1/21	W Pacific	2480	0.00%
1/23	W Pacific	3643	2.25%
1/26	W Japan	1033	1.45%
1/28	Sea of Japan	3212	1.00%
1/29	Sea of Japan	3421	2.22%
1/30	Sea of Japan	3824	2.01%
2/1	W Japan	1870	1.39%
Total		37165	509



LISA Initial Results Summary

- Campaign produced 8 GB of data: initial software developed to auto-detect large "pulses" > 200 stds above mean
- Results sorted manually to find interferers localized in time/frequency
- Analysis continues for other types and weaker amplitude interferers
- Detailed examination of 1411-1425 MHz channel shows numerous triggers, but signal properties are difficult to classify



- Captures useful for testing effectiveness of suppression algorithms

Conclusions

- Interference mitigating radiometer prototype developed; detailed tests in progress to quantify performance
- L-band RFI surveys performed with LISA system; results show a variety of RFI types; useful for refining algorithms
- Technologies developed can be applied at other frequencies; prototype operating at C-band being discussed with NPOESS
- Use of these technologies in space seems feasible, although power, weight, etc. will require some work
- Discussions of co-flights, possible collaborations, etc. are welcomed; digital backend could be interfaced to many systems